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RESEARCH ARTICLE

Use of Constructed Wetlands to Reduce Pollution of Surface Waters by Tea Factory Effluent in Nandi Hills Tea Estates in Kenya

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Abstract

The study aimed at investigating the efficiency of treating tea factory effluent using constructed wetlands in Nandi Hills Tea Estates, Kenya. Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were determined in tea factory effluent. Dissolved nitrates and phosphates were analyzed in stream water samples using standard methods for sampling and analysis. Results showed that untreated tea factory effluent had high levels of COD (6732 to 14800 mg/L) and TSS (1078 to 3400 mg/L), and a moderate level of BOD (44 to 53 mg/L). These values reduced after treatment with more than 95% of TSS and COD and 80% of BOD removed by the constructed wetlands. Removal efficiencies for the heavy metals; Cd, Pb, Cu and Zn, were 7.1%, 80.0%, 95.1% and 100% respectively. The high concentration of nitrates (6.6 ± 2.1 mg/L) in a stream receiving factory effluent, compared to the receiving river (0.6 ± 0.7 mg/L) showed that some improvements were needed on the wetlands. The study recommends that sludge flushed out of the sedimentation basin should be directed to a sand bed for filtration and drying and the effluent passed on to the surface cells where more bio-degradation would take place. A mechanism to remove colour from the effluent should also be explored to reduce the turbidity of receiving waters.

Key Words: Constructed Wetlands, Tea Factory Effluent, Water Quality, Nutrients, Heavy Metals, Water Pollution

Introduction

Performance of Constructed Wetlands

A constructed wetland system for wastewater treatment is designed to mimic the natural wetland treatment processes by Mother Nature. This system uses plants and microbes to improve the wastewater quality. Constructed wetlands for wastewater treatment may be classified according to the life form of the dominating macrophytes into: Free-floating macrophyte-based systems, Submerged macrophyte-based systems, and rooted emergent macrophyte-based systems. According to water flow, different rooted emergent systems are distinguished into surface flow systems, horizontal subsurface flow systems, and vertical subsurface flow systems. Rooted emergent aquatic macrophytes are the dominant life forms in wetlands growing within a water-table ranging from 50cm below the soil surface to a water depth of 150cm or more (Brix, 1993). The most powerful combinations are those that couple horizontal and vertical submerged flow beds, called hybrid systems (Masi & Martinuzzi, 2007). The surface area for constructed marshes ranges from 24.6 to 39.6 m^2/m^3 of applied wastewater per day. Constructed wetlands that discharge to surface water require 4 to 10 times more land area than a conventional wastewater treatment facility (U.S. Environmental Protection Agency, 1998).

Shallow sub-surface flow constructed wetlands (0.27 m) remove organic matter and nitrogen at very high rates than deeper beds (0.5 m) (Osorio, 2006). In sub-surface flow constructed wetlands, suspended solids and particulate organic matter are removed quickly by means of physical processes such as sedimentation, adsorption and entrapment. Subsequently, the hydrolyzed portion of the particulate matter is oxidized by means of aerobic and anaerobic processes including aerobic respiration, denitrification, sulfate reduction and methanogenesis (Osorio, 2006). Nitrogen is removed by nitrification/denitrification. Ammonia is oxidized to free nitrogen in the anoxic zones by denitrifying bacteria. Denitrification readily occurs in wetland systems where sufficient dissolved carbon is present (Watson et al, 1989). The aquatic plants themselves bring about little actual treatment of the wastewater. Their function is generally to support components of the aquatic environment that improve the wastewater treatment capability and/or reliability of that environment. Bacteria attached to plant stems and the humic deposits are the major factor for BOD_5 removal (U.S. Environmental Protection Agency, 1998).

Removal efficiencies for BOD_5, COD, TSS and NH_3 as shown by Khisa (1997) for the constructed wetland at carnivore Restaurant in Nairobi, of a similar design as the one's being studied, were 96%, 97%, 84% and 41% respectively in dry weather. The performance of a hybrid system (coupling horizontal and vertical submerged flow beds) recorded mean removal rates of COD 94%, BOD_5 95%, total suspended solids 84%, NH_4^+ 86%, total nitrogen 60% and total phosphorus 94% (Masi & Martinuzzi, 2007).

Using experimental scale Gravel Bed Hydroponics planted with *Penisetum purpureum*, *Brancharia decumbens*, and *Phragmites australis*, Mant et al (2005) reported that *P. purpureum* was most effective (97 – 99.6 removal efficiency) in removing chromium from tannery wastewater although treatment methods such as ion exchange or reverse osmosis are more efficient. Liao and Chang (2004) found water hyacinth (*Eichhornia crassipes* Mart. Solms.) to be a promising candidate for phytoremediation of wastewater polluted with Cu, Pb, Zn, and Cd. The absorption capacity for water hyacinth was estimated at 0.24 kg/ha for Cd, 5.42 kg/ha for Pb, 21.62 kg/ha for Cu, 26.17 kg/ha for Zn, and 13.46 kg/ha for Ni. Special organic compounds also be removed by constructed wetlands (Haberl *et al*., 2003).

Objective

Effluents from tea factories in Nandi Hills are a possible source of pollution to streams with nitrates (Othieno, 1992). Organic matter (BOD/COD) reduces dissolved oxygen in the streams thus interfering with the self-purification processes. Constructed wetlands are being constructed to solve this problem and there was need to know their performance.

This study investigated the concentration of BOD, COD, TSS and heavy metals in the effluent of two tea factories (Chemomi and Kapsumbeiwa) in Nandi Hills. The pollutant removal efficiency of the constructed wetlands was then assessed. The impact of the effluents on surface waters (stream and rivers) was investigated by comparing the concentration of nutrients (NO_3^--N and PO_4^--P) and heavy metals (Cd, Pb, Cu and Zn) in streams receiving factory effluents with those not directly polluted with factory effluent.

Material and Methods

Study Area

Nandi Hills is found in Nandi South District located on the highlands west of the Rift valley in Kenya (Ministry of Finance and Planning, 2001) within latitude 0^0 and $0^0$34' North and longitudes 34^0 44' and 35^0 25'. The study area (Figure 1) is located at the catchment area of River Mokong which is a major tributary of River Yala that drains in to Lake Victoria. Large tea estates cover much of the division. The study area has at least 7 tea factories. Average annual rainfall between the years 2000 and 2002 was 1425 ± 192 mm. The month with the highest rainfall was May (183 ± 81 mm) and the least rainfall was in February (31 ± 12 mm). Samples were collected during the low rainfall season in the Months of November, January and March. During the years 2001 and 2002, the months with the highest temperatures (18 ± 0.4^0C) was February while the lowest temperatures (15.1 ± 0.4^0C) was recorded in August (Eastern Produce (K) Ltd).

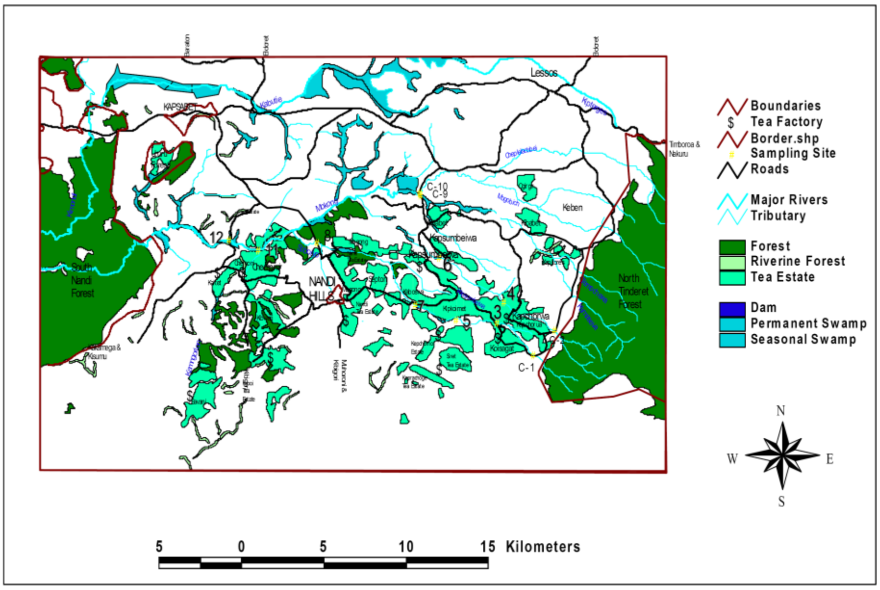

Figure 1. Location of Sampling Site in Nandi Hills Tea Estates

Experimental Design

The constructed wetlands at Chemomi and Kapsumbeiwa tea factories were the ones used in this study. The treatment stages include screening, sedimentation, sub-surface horizontal flow in a Gravel Bed Hydroponics system (Plate 1) and three Surface Cells (shallow meandering ponds approximately 3 m x 15 m with various aquatic plants including water lettuce and duckweeds). For the Gravel Bed Hydroponics, the emergent macropytes are often harvested to increase uptake of pollutants from the effluent.

Plate 1. Gravel Bed Hydroponics at Chemomi Factory Constructed Wetland, Nandi Hills

Effluent samples were collected from Chemomi and Kapsumbeiwa factories in duplicate as the effluent leaves each of the treatment stages (Screening, Sedimentation, Gravel Bed Hydroponics and Surface Cells 1, 2 and 3) in the drier months of January 2003 and March 2003 when there is less interference from surface runoff. Only samples representing untreated influent and the effluent after screening stage were available at Kapsumbeiwa factory whose constructed wetland was commissioned in January 2003 and is yet to flow into the surface cells. Duplicate stream water samples were also obtained from a stream receiving Chemomi factory effluent and from neighboring streams for comparison as shown in the Figure 1 below. Standard methods of sampling stream water and effluent were followed. Dissolved oxygen, temperature, pH and conductivity were determined in situ using electronic meters with specific sensors (Bartram & Ballace, 1996). Table 1 gives a description of the sampling sites.

Table 1. Description of Sampling Sites

Sampling sites	Description (See Figure 1)
Controls: C-1 and C-2	Sampling sites are along Soboiyo and Kapsumbeiwa streams as the streams are entering tea estates from North Tinderet forest
3 and 4	Sampling sites are upstream as Soboiyo and Kapsumbeiwa streams flow out of impoundments within tea estates
5 and 6	Sampling sites are downstream as Soboiyo and Kapsumbeiwa streams flow through the tea estates
7	Sampling site is downstream as Soboiyo stream flows out of an impoundment in the tea estates
8	Sampling site is along Soboiyo stream as the stream flows out of the tea estates
Controls: C-9 and C-10	Sampling sites are along Kibabet and Mogobich / Cheplelachbei streams flowing from sources outside the tea estates
11	Sampling site is along Chemomi stream that contains Chemomi factory effluent just before discharging into River Mokong
12	Sampling site is along River Mokong after receiving water from all streams

Preparation and Analysis of Samples

Effluent samples with high COD were diluted 10 times before analysis before oxidizing with potassium dichromate and titrating with ferrous ammonium sulphate (Bartram & Ballace, 1996). BOD_5 was determined using a Dissolved Oxygen meter following incubation (Bartram & Ballace, 1996). 0.45µm pore size membrane filters were used to determine TSS (Bartram & Ballace, 1996). Analysis of heavy metals was by flame atomic absorption spectrophotometry after digesting with nitric acid (APHA, AWWA and WEF, 1992). The Cadmium Reduction and Ascorbic Acid Methods were followed to analyze for dissolved nitrates (NO_3^--N) and phosphates (PO_4^--P) in stream water samples (Bartram & Ballace, 1996). The reagents were contained in powder pillows (Hach Company, 1989).

Results

The effluent received at the Kapsumbeiwa and Chemomi constructed wetlands from the factory is approximately 23,000 and 11,520 litres/day respectively between Tuesdays to Sundays and approximately 58,000 and 28,800 litres/day respectively on Mondays. Discharge decreases after each treatment stages. Chemomi factory discharged a mean of 0.8±0.5 litres/sec of effluent between 24/2/2003 and 14/3/2003. On average, the effluent decreases to 0.4 liters/sec after subsurface flow in a Gravel Bed Hydroponics system and thereafter to 0.3±0.2, 0.2±0.1 and 0.1±0.0 litres/sec after surface cells 1, 2 and 3 respectively. The flow rate was determined by measuring the amount of effluent received in a container per minute.

BOD, COD, TSS and True Colour all decreased gradually after each of the 6 treatment stages shown in Figure 2. Influent BOD decreased from 48±5 mg/L to 9±8 mg/L after treatment, COD decreased from 9677±4453 mg/L to 241±57 mg/L, TSS decreased from 2326±1171 mg/L to 97±4 mg/L and Colour from 6313±2783 Pt Colour Units to 2274 ± 648 Pt Colour Units. pH increased from 6.2±0.1 to 7.1±0.2 between the Gravel Bed Hydroponic and Surface Cell 2. Conductivity decreased steadily from 486±6 µS/cm at surface cell 1 to 281±51 µS/cm at surface cell 3.

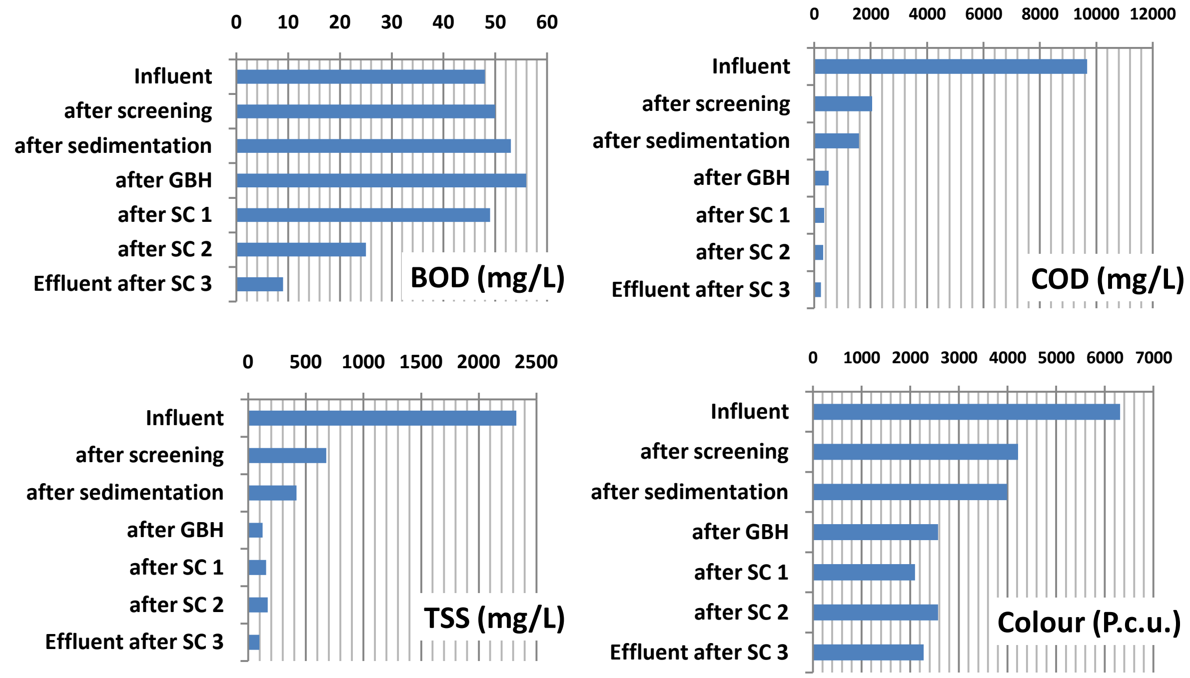

Figure 2. Concentrations of TSS, COD, BOD and Colour in Tea Factory Effluent as it Flows through the Constructed Wetlands

The stream receiving factory effluent from Chemomi factory had the highest concentration of nitrates (6.6±2.1 mg/L) at sampling site 11 just before the stream discharges into River Mokong. The concentration was approximately 11 times greater compared to the level of nitrates in River Mokong at sampling site 12 (0.6±0.7 mg/L). As shown by Figure 3, apart from sampling site 11, most other sampling sites had both the nitrates and phosphates levels below 1 mg/L. The nitrogen to phosphorus ratio (N/P) was highest at sampling site 11 (N/P = 28) and lowest at the control sampling sites C-2, C-9 and C-11 (N/P = 1, 0 and 1 respectively) that are at points along streams not yet impacted by tea cultivation.

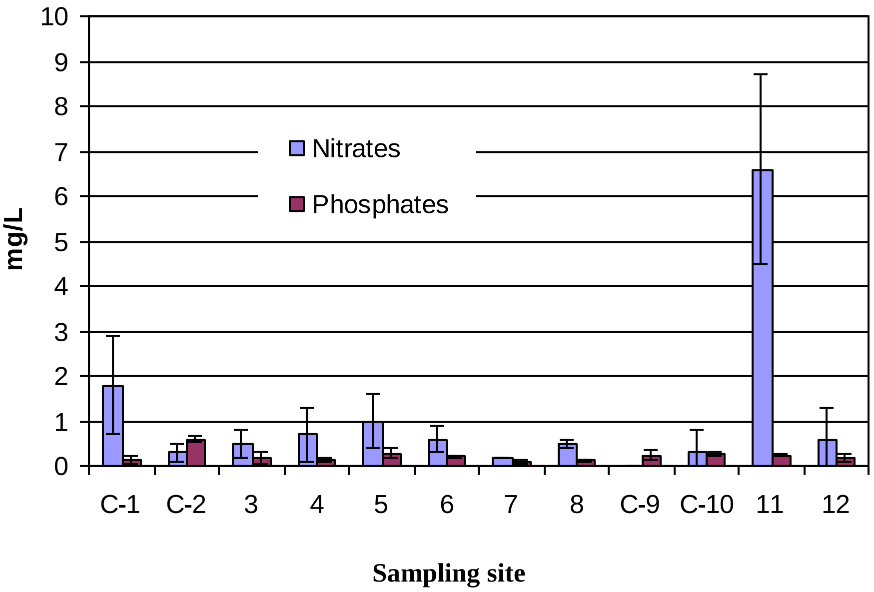

Figure 3. Concentration of Nitrates and Phosphates in Streams Flowing through Tea Estates Compared to Controls

Figure 4 shows that the concentration of Pb, Cu and Zn in the influent decreased gradually as the effluent flowed through the 6 treatment stages. Pb decreased from 0.05±0.04 mg/L to 0.01±0.00 mg/L, Cu decreased from 0.102±0.07 mg/L to 0.005±0.007 mg/L and Zn decreased from 0.445±0.196 mg/L to 0.000 mg/L (below detection limit). Cadmium decreased drastically from 0.014±0.009 mg/L to 0.005±0.001 mg/L at the sedimentation stage but thereafter rose back to 0.013±0.006 mg/L. The removal efficiencies for Pb, Cu, Zn and Cd were 80%, 95%, 100% and 7% respectively. Figure 5 shows the concentration of Cd, Pb, Cu and Zn in factory effluent compared to the concentration in streams.

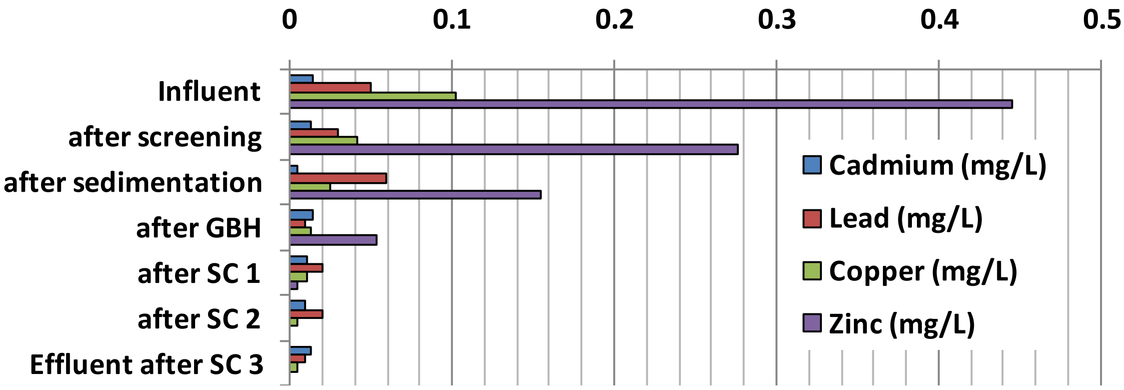

Figure 4. Concentrations of TSS, COD, BOD and Colour in Tea Factory Effluent as it Flows through the Constructed Wetlands

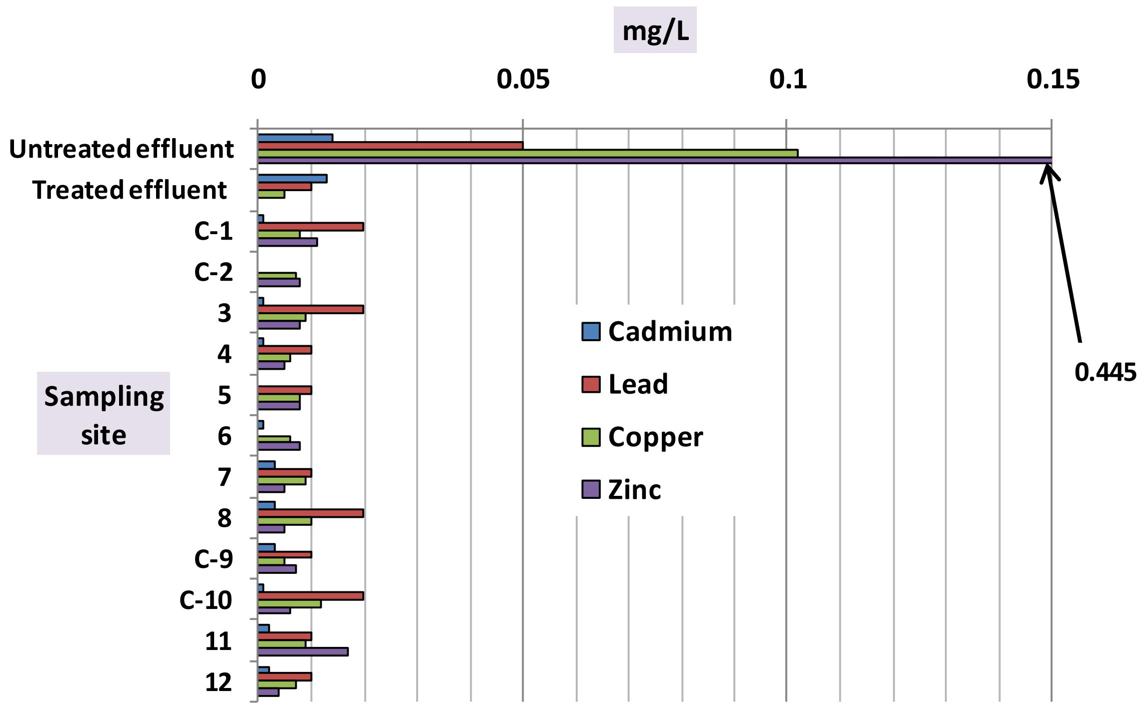

Figure 5. Concentration of Cd, Pb, Cu and Zn in Factory Effluent Compared to the Concentrations in Streams

Discussion

Performance of Constructed Wetlands

In about 4 hours each day, an average of approximately 12,000 and 23,000 liters of effluent is discharged from Chemomi and Kapsumbeiwa tea factories respectively to Constructed Wetlands. On Mondays when there are major cleaning operations at the factories, discharge increases to approximately 30,000 and 58,000 liters respectively, flowing 10 hours per day. At Chemomi wetland, almost no effluent flows out of the last treatment stage during the drier months of Feburary and March. This reduction could be as a result of underground seepage since the constructed wetland, commissioned only two years ago, does not have an impervious bottom layer. The reduction could also be as a result of evaporation. Final discharge after surface cell 3 however increases following increased rainfall and runoff. At the sedimentation tank, accumulated sludge is usually flushed out as a routine. There is no Dry Bed to recover this sludge (mainly decomposing tea leaves) which therefore flows downhill to pollute Chemomi stream with nitrates.

As shown in Figure 2, the screening stage is very effective in the removal of COD and TSS while the surface cells are effective in the removal of BOD_5. The removal efficiencies for BOD_5, COD, TSS and Colour are 81.3%, 97.5%, 95.8% and 64.0% respectively. TSS are mainly crushed tea leaves that are the source of COD. Khisa (1997) found that the removal efficiency of Carnivore Restaurant Constructed Wetland was 96%, 97% and 84% for BOD_5, COD and TSS respectively. The TSS removed is mainly tea leaves containing approximately 3 to 4% N (Fuchs, 1989). If these were left to flow into the Gravel Bed Hydroponics and Surface Cells, it would result in significant nitrogen loading. Harvesting macrophytes removes less than 20% of influent nitrogen. Constructed wetlands can be designed to remove nitrogen, if sufficient aerobic (open water) and anaerobic (vegetated) zones are provided. Otherwise, constructed wetlands should be used in conjunction with other aerobic treatment processes that can nitrify to remove nitrogen (US Environmental Protection Agency, 2000).

According to the Maximum allowable limits set by the Environmental Management and Co-ordination (Water Quality) Regulations (National Environment Management Authority, 2006), BOD_5 at 20^{o}C, COD, TSS and Colour in effluent should not exceed 30 mg/L, 50 mg/L, 30 mg/L and 50 Pt Colour Units respectively. The constructed wetland can therefore be said to have led to the factory effluent having a BOD concentration (9 ± 8 mg/L) within the recommended standards. However, more has to be done to reduce Colour (2274 ± 648 Pt Colour Units), COD (241 ± 57 mg/L) and TSS (97 ± 4 mg/L). pH drops slightly from 6.8 when the effluent flows through the GBH to 6.2 possibly due to addition of humic acid from decomposing organic matter and rises slowly to 7.1 at surface cell 2 to finally flow out of surface cell 3 at a pH of 6.9. pH of final effluent is within the recommended standard of 6.0 to 8.5 (National Environment Management Authority, 2006).

Removal efficiencies for Cd, Pb. Cu and Zn are 7.1%, 80.0%, 95.1% and 100% respectively. According to Momanyi (2002) the concentrations of Cd, Pb, Cu and Zn in PanPaper Mills effluent are 0.028, 0.023, 0.043 and 0.055 mg/L respectively. These levels are higher than the concentration of Cd, Pb, Cu and Zn in effluent from Chemomi and Kapsumbeiwa constructed wetlands (0.013±0.006 mg/L, 0.01±0.00 mg/L, 0.005±0.007 mg/L and a level below detection limit respectively). As shown by Figure 4, the constructed wetlands effectively reduced the concentration of Pb, Cu and Zn to a level comparable to that of streams. The maximum allowable concentration of Cd and Pb in effluent according to the Environmental Management and Co-ordination (Water Quality) Regulations (National Environment Management Authority, 2006). is 0.01 and 0.01 mg/L respectively. Effluent from Chemomi and Kapsumbeiwa factory wetlands meets these standards.

Experimental gravel beds grown with *Penisetum purpureum* and *Brancharia decumbens* have shown chromium removal efficiencies of 97 – 99.6% within 24 hours. 97 – 98% of all the chromium taken up by the plants during the experiment remained below ground, in/on the roots. *Phragmites australis* never looked healthy in the system and it was concluded that that the 12.8 mg Cr dm^{-3} found in its leaves was above its phytotoxicity threshold. (Mant *et al.,* 2005).

Water Quality in Streams

Chemomi stream, that contains effluent from Chemomi factory, is polluted with nitrates. The concentration of NO_3^--N in this stream at sampling site 11 (just before the stream discharges into River Mokong) is 11 times higher than the concentration in River Mokong at sampling site 12. In the absence of the existing Constructed Wetland to treat the factory effluent, the level could have been much higher. Nitrate toxicity should be avoided because it can lead to methemoglobinemia, a condition where transport of oxygen in the blood of infants is inhibited (Follet & Walker, 1989), or abortions in ruminants (Water Research Commission, 2005). All other sampling sites had concentration of NO_3^--N below 10mg-1, the recommended drinking water standard (National Environment Management Authority, 2006). The average concentration of Cd (0.002±0.001 mg/L), Pb (0.003±0.005 mg/L), Zn (0.008±0.004 mg/L) and Cu (0.008±0.004 mg/L) in the streams within the tea estates were within the recommended drinking water standards.

Streams flowing into the tea estates generally have low N/P ratios compared to the N/P ration at sampling sites within the tea estates. Compound fertilizers such as NPK are generally used to re-fertilize the soil in tea estates. It is probable that these fertilizers and factory effluent are a major source of higher levels of nitrates in the streams and rivers flowing through Nandi Hills tea estates compared to the controls. This may be a reason why some impoundments along the streams are exhibiting euthrophication. According to Othieno (1992), rainfall intensity, soil wetness and land steepness are three major factors that contribute to soil erosion on tea lands. Runoff and soil erosion is severe in the early stages of development of the young tea plants, especially the period between land preparation and the end of the first two years of planting. However, once the tea plants have developed a uniform ground cover canopy of 60% or above, both runoff and soil erosion becomes negligible.

Conclusions and Recommendations

Conclusions

Tea factory effluent has high levels of COD, BOD, TSS and Colour as tea leaves are washed away from processing machinery during cleaning operations. Tea leaves lead to high concentration of nitrates in receiving streams. The Constructed Wetlands are efficiently reducing pollution of streams by removing COD, BOD, TSS and Colour. This ultimately reduces the level of pollutants in surface water. However, COD, TSS and especially Colour still remain high in the final effluent after treatment.

The constructed wetlands are not designed to recover sludge from the sedimentation tanks. Sludge lost to the environment may flow to the streams increasing the concentration of TSS, COD, BOD and nitrates in addition to other pollutants.

Tea factory effluent contains organic matter that contaminates streams with nitrates thereby posing a public health concern of methemoglobenemia. For example, Chemomi stream is polluted with nitrates the source of which is Chemomi factory effluent. The concentration of nitrates in this stream approached the maximum allowable limit in drinking water set by WHO (UNESCO, WHO & UNEP, 1992) and Kenya (National Environment Management Authority (2006).

Recommendations

The constructed wetland at Chemomi factory and other wetlands designed similarly can be improved by recovering the sludge from the sedimentation stage that is at present being released to streams. The efficiency of the constructed wetlands can be improved by constructing Drying Beds to recover sludge that can be used as manure. Regular removal of macropytes, which can be used as manure, is encouraged. A hybrid system (coupling horizontal and vertical submerged flow beds) may also show better performance.

A treatment stage to remove Colour from the wastewater flowing through the constructed wetland should be developed. Removal of colour would improve the treatment efficiency of the surface cells due to increased activity of phytoplankton.

References

APHA, AWWA, & WEF (1992). "Standard Methods for the Examination of Water and Waste Water", 18th Edition. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), Washington, D.C.

Bartram, J., & Ballace, R. (eds), (1996). "Water Quality Monitoring; A Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes". UNEP, WHO and Chapman and Hall, London, 383 p.

Brix, H. (1993). Waste Water Treatment in Constructed Wetlands: System Design, Removal Processes and Treatment Performance In: Moshiri, G.A. (Ed.) "Constructed Wetlands for Water Quality Improvement", Lewis Pub, Boca Raton.

UNESCO, WHO & UNEP (1992). "Water Quality Assessments: A guide to the Use of Biota, Sediments and Water in Environmental Monitoring". Chapman and Hall, London.

Eastern Produce (K) Ltd. Unpublished Technical Department Records

Follett, R. F., & Walker, D. J. (1989). Ground Water Quality Concerns about Nitrogen. In: Follet, R. F. (Ed). "Nitrogen Management and Ground Water Protection". Elsevier: Amsterdam.

Fuchs, H. J. (1989). "Tea Environments and Yield in Sri Lanka". Morgranf Scientific pub.

Haberl, R., Grego, S., Langergraber, G., Kadlec, R.H., Cicalini, A., Dias, S. M., Novais, J. M., Aubert, S., Gerth, A., Thomas, H. and Hebner, A., (2003). "Constructed Wetlands for the Treatment of Organic Pollutants". Review Article with Case Studies. JSS – J Soils & Sediments 3 (2) 109 – 124. Ecomed publishers, Landsberg. Accessed at

Hach Company (1989). "Hach Water Analysis Handbook". Hach Company, Loveland.

Khisa, K. (1997). "The Performance of a Constructed Wetland for Treating Wastewaters at Carnivore Restaurant Nairobi, Kenya". M.Phil Thesis, Moi University, Kenya.

Government of Kenya (2001). "Nandi District Development Plan, 2002 – 2008". Ministry of Finance and Planning.

Liao, S., & Chang, W. (2004). Heavy Metal Phytoremediation by Water Hyacinth at Constructed Wetlands in Taiwan. J. Aquat. Plant Manage. 42: 60-68. http://www.apms.org/japm/vol42/v42p60.pdf

Mant, C., Costa, S., Williams, J., & Tambourgi, E. (2005). "Studies of Removal of Chromium by Model Constructed Wetland." Brazilian Journal of Chemical Engineering. Vol. 22, No. 03, pp. 381 – 387.

http://www.scielo.br/pdf/bjce/v22n3/25934.pdf

Masi, F. & Martinuzzi, N. (2007). "Constructed wetlands for the Mediterranean countries: hybrid systems for water reuse and sustainable sanitation". Elsevier. Desalination 215 (2007) 44–55. http://www.iridra.eu/pubblicazioni/CWs%20in%20the%20Mediterranean%20countries.pdf

Momanyi, T. M. (2002). "Studies on Selected Water Quality Parameters and Heavy Metals in Pulp and Paper Effluents in Relation to the Pollution of the River Nzoia at Webuye". M. Phil Thesis, Moi University, Kenya.

National Environment Management Authority (2006). "Environmental Management and Co-ordination (Water Quality) Regulations". Legal Notice No. 120 of 2006. http://www.nema.go.ke/images/stories/pdfs/water_quality_regulations.pdf

Osorio, A. C. (2006). "Influence of the Characteristics of Organic Matter on the Efficiency of Horizontal Subsurface-flow Constructed wetlands". Thesis presented as partial requirement to obtain the title of doctor (Ph D) at the Technical University of Catalonia. Castelldefels. http://www.tesisenxarxa.net/TESIS_UPC/AVAILABLE/TDX-0222107-124705//01Aco01de01.pdf

Othieno, C. O. (1992). Soils. In: Willson, K.C. & Clifford, M.N. (Eds) "Tea Cultivation to Consumption". Chapman and Hall, London.

U.S. Environmental Protection Agency (1998). "Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Water Treatment." Office of Research and Development, EPA/625/1-88/022. http://www.hydrik.com/downloads/WetlandsDesign_Hydrik.pdf

U.S. Environmental Protection Agency (2000). "Manual. Constructed Wetlands Treatment of Municipal Wastewaters". Office of Research and Development, EPA/625/R-99/010. Accessed at http://www.epa.gov/nrmrl/pubs/625r99010/625r99010.pdf

Water Research Commission (2005). "Ground Water Pollution: When Water Turns Deadly - Investigating Nitrate in SA Groundwater". The Water Wheel, p24-27. http://www.wrc.org.za/archives/waterwheel%20archive/nov-dec%2005/Nitrate%20p%2024-27.pdf

Watson, J. T., Reed, S. C., Kadlec, R. H., Knight, R. L., & Whitehouse, A. E. (1989). Performance Expectations and Loading Rates for constructed Wetlands. In: Hammer, D.A. (Eds.) "Constructed Wetlands for Waste Water Treatment; Municipal, Industrial and Agricultural". Lewis Pub., Michigan.